

SECTION 10 – RESEARCH AND EDUCATION

Research and development (R&D) will continue to drive innovation and growth in Virginia's advanced energy industry. To maximize the value and impact of R&D, Virginia can build on its strong base of existing research institutions and innovative companies to create and attract new businesses, build Virginia's workforce, and solve environmental and energy challenges. Pursuing federal research dollars can multiply the impact of Virginia's own expenditures and investments. Virginia is already 3rd in the nation in terms of overall federal R&D funding, based on the latest data available.



State-of-the-art technology and systems are required for the Commonwealth to effectively compete on a national and global scale. But there cannot be successful adoption of advanced energy technology and processes without this key demand driver in place: a formidable Virginia workforce that is appropriately skilled, experienced, innovative, and highly adaptable.

The U.S. Bureau of Labor Statistics' Virginia Green Workforce Estimates are skewed heavily to U.S. military and federal government employment. With these jobs removed, the

Commonwealth's green jobs concentration drops to an unremarkable 2.6 percent share of workforce. As is the case with workforces in other states, the number of Virginians employed in green jobs remains relatively small, at 2.6 percent of workforce, perhaps an estimated 100,000 Virginians--from within a population of 8.3 million people.

Virginia can reduce barriers to innovation, and make more of the opportunities and substantial scientific and technical resources it has already developed. One of the most important recurring elements is finding new ways to secure existing federal R&D funds and if possible expand Virginia's share to counter shrinking federal investment. In addition, Virginia should demonstrate Energy Incubators and expand on initial results by providing state support and funds to emerging energy technology incubators, such as the spin-off smart grid companies attracted to Virginia Tech and Blacksburg.

Current Environment in Research

There is a State role in bringing together research and businesses based on new technology and services with Virginia's major energy businesses to develop applications and markets that will serve Virginia's changing energy and environmental needs. Research, Development and Demonstration (RD&D) is essential to growth and productivity in the energy industry just as it is for the information technology, biotechnology, communications, medical and other sectors. Clean energy integration into the existing energy system is an important target of opportunity for research and demonstration. There is also fruitful RD&D for specific energy technologies, Virginia interests align very well with national research programs in solar energy, wind, bioenergy, hydropower, building efficiency technologies, smart grid, advanced vehicles and

advanced manufacturing. The Department of Defense (DoD) is investing heavily in developing and deploying new energy technologies to reduce the agency's environmental impact and become more resilient.

Virginia is already one of the largest recipients of Federal R&D expenditures, 14th in terms of funds from the Department of Energy, 2nd in terms of DoD funding, and 3rd in overall Federal R&D funding in 2010.¹ Virginia has a concentration of high-technology companies involved in Federal contracting and world-class universities that are already engaged in clean energy development including the Center for Smart Power Grids at George Mason University, the Virginia Coastal Energy Research Consortium at Old Dominion University, the Center for Catalytic Hydrocarbon Functionalization at the University of Virginia, and the Institute for Energy and Environmental Research at James Madison University.² Virginia Tech has several leading research centers.³ The Center for Energy Systems Research, The Macromolecules and Interfaces Institute and the Future Energy Policy Center all work on hydrogen fuel cells. The Center for Intelligent Materials Science and Structures, The Center for Photonics Technology (detection and diagnostics for electrical equipment), The Center for Power Electronics Systems (advanced electronic power conversion and power electronics) and the Consortium on Energy Restructuring are all broadly involved in energy infrastructure research. In energy efficiency and conservation Virginia Tech includes The Center for Turbo Machinery and Propulsion Research and the Multidisciplinary Analysis and Design Center. The Center for Energy and the Global Environment and the Conservation Management Institute encompass work on wind, solar, hydroelectric and biomass energy.

Virginia Tech also hosts the Virginia Center for Coal and Energy Research which is one of the institutions leading carbon sequestration research in Virginia including the Southeast Regional Carbon Sequestration Partnership (SECARB). SECARB is one of seven DOE-funded regional partnerships developing carbon sequestration. This is important clean energy research that has the potential to solve at least part of the largest barrier to Virginia's continued reliance on coal, climate change.

Dominion Virginia Power recently received a \$47 million grant from DOE to demonstrate innovative technologies to reduce off-shore wind costs.⁴ Dominion is one of 22 firms selected under a \$7 billion multiple award task order contract (MATOC) for the Army to obtain solar energy through private sector financing,⁵ and was also selected for a parallel \$7 billion wind MATOC, which together will create opportunities for Dominion to apply solar and wind technologies on a large scale for one of the largest energy customers in Virginia, the DoD.⁶

¹ TABLE 85. Federal obligations for research and development, by state and other locations and selected agency: FY 2010, Federal Funds for Research and Development: Fiscal Years 2010–12. July 2013. National Science Foundation National Center for Research Statistics. NSF 13-26.

² Weigman, Leo; Preefer, Alexandra; Santana, Jose Miguel; & Vosmeir, Liz. National Guide to State Research Centers, 2011-2012. 2013. Association of State Energy Research and Technology Transfer Institutions.

³ Centers and Groups Doing Energy Research. May 7, 2014. Retrieved from www.research.vt.edu/energy/energycenters.html. Virginia Tech.

⁴ Coy, Brian. "Governor McAuliffe Statement on U.S. Department of Energy Grant Award to Dominion Virginia Power for Wind Energy Demonstration Program." May 7, 2014. Press release from Office of Governor Terry McAuliffe.

⁵ Army Selects 22 Solar Contractors under \$7B MATOC. September 2, 2013. Association of Defense Communities website. Retrieved from www.defensecommunities.org/headlines/army-selects-22-solar-contractors-under-7b-matoc/#

⁶ Army awards third technology, wind, under \$7 billion renewable energy MATOC. September 10, 2013. www.army.mil, the official webpage of the U.S. Army. Retrieved from www.army.mil/article/111010/Army_awards_third_technology__wind__under__7_billion_renewable_energy_MATOC/

Potential

Clean energy integration into the existing energy system is an important target of opportunity for research and demonstration. There are plenty of clean energy generation, efficiency and conservation technologies that are cost-effective or near cost-effective but their full potential is limited by the difficulty of integrating them into current regulated and competitive energy markets. Alternative transportation fuels, including electric vehicles, are limited by the need to invest in refueling infrastructure in competition with the mature refueling network for gasoline and diesel. Renewable electric generation is dependent on local resources, and for intermittent resources like wind and Photovoltaic (PV) solar the ability to integrate with the grid to act as storage and backup when the resource is not available.

A major focus of smart grid research is adapting to high penetration of intermittent renewables by leveraging micro-grids, storage, and most important the 2-way communications and control and intelligence that makes coordination between generation and demand management resources possible. Virginia Tech and the Blacksburg smart grid demonstration are internationally recognized contributors to this field that could be a model for expanded research, development and demonstration in Virginia and a starting point for using research to incubate new clean energy businesses to design and supply the smart grid. New areas of development could include improved short-term forecasting for grid management (see the Northwest Transactive Control activities in their Smart Grid Demonstration as an example, www.pnwsmartgrid.org/), 2-way integration of Electric Vehicles (EV) and Plug-In Hybrid Electric Vehicles (PHEV) to provide electric storage (see DOE Clean Cities demonstrations and work at Argonne National Laboratory). Non-electric energy applications including thermal energy and alternative transportation fuels also need work on integration and competition with existing systems. Virginia has a start in the use of compressed natural gas for fleets and bus transport, and modest use and development of biofuels.

Current Environment in Education

Despite all of the quality instruction, training, and certification/accreditation available in Virginia, these resources are not tied together, properly integrated, nor, are they led by the clean energy industry to ensure that we build the workforce that they need, ready when needed.

Our higher education research and instructional advantages extend far. Over 20 of our colleges and universities provide excellent Bachelor and advanced degree programs in Engineering and Business Administration with course concentrations in Environmental Science. Further, our institutions may extend their specialized instruction and training through clean energy research, development, and demonstration (RD&D) projects.

Energy Research and Development

New energy sources and technologies are crucial to achieving energy independence and security and to providing affordable and reliable sources of energy with limited environmental

impact. Targeted energy research and development (R&D) and its effective deployment are critical to meeting Virginia's future energy needs and those of the nation. By enabling energy innovation and commercialization, the Commonwealth has the opportunity to deliver manifold environmental and economic benefits.

Virginia boasts a vibrant, diverse energy research community. Leading energy R&D is underway in academia, industry, and federal laboratories in Virginia, in a broad range of technologies and applications important to the Commonwealth and globally. Virginia's energy assets include nationally and internationally recognized researchers, centers, and laboratories, including those with unique or distinctive equipment required in energy R&D.

The National Science Foundation (NSF)'s 2011 Science and Engineering State Profiles ranked Virginia #12 among states in federal Department of Energy (DOE) R&D obligations. Virginia colleges and universities' 2011 DOE R&D obligations of \$17.98 million were approximately 1.8 percent of the total received by U.S. colleges and universities, \$1.01 billion⁷. Virginia's federally-funded energy R&D is in fact larger, as many federal agencies and organizations, other than DOE, also support energy R&D. These other agencies include the Department of Defense (DOD), the Department of Transportation (DOT), and NSF. Energy R&D also is supported by such other sources as universities themselves, foundations, the private sector, and the Commonwealth, including through the Department of Mines, Minerals and Energy (DMME) and the Commonwealth Research Commercialization Fund (CRCF) administered by the Center for Innovative Technology (CIT).

Energy R&D in academia, industry, and federal laboratories in Virginia overlaps in many sectors, particularly in clean and renewable energy. Specific areas include next generation biofuels; smart grid; offshore wind; efficiency and conservation; solar; energy storage, including fuel cells; and nuclear technologies. Substantial research in coal and energy policy continues in Virginia.

Virginia's federal laboratories have a long-standing interest in energy and perform research that supports their missions. Interests of the Thomas Jefferson National Accelerator Facility (Jefferson Lab), the Naval Surface Warfare Center Dahlgren Division (NSWCDD), and the NASA Langley Research Center (NASA LaRC) include nuclear, fuel cells, alternative fuels, and energy efficiency.

Significant energy research also is being performed by Virginia industry. Dominion Virginia Power was awarded \$47 million in continued funding in May 2014 by DOE to continue a 12-megawatt offshore wind turbine generator demonstration project off the coast of Virginia⁸. AREVA and Babcock & Wilcox are leaders in nuclear. Newport News Shipbuilding and Opower are other large companies investing in R&D. Small early-stage companies are advancing a number of new technologies, supported in part by federal Small Business Innovation Research (SBIR) and Small Business Technology Transfer Research (STTR) funding as well as public and private investment.

Finally, there is a new and growing source of energy R&D within the Commonwealth originating from entrepreneurs with start-ups aiming to capitalize "garage" technologies or, in other instances, those spun out from a research institution via a licensing mechanism. The

⁷ National Science Foundation, *State Agency Expenditures for R&D, Fiscal Year 2011*, Detailed Statistical Table 19 (2014).

⁸ Dominion Virginia Power. (2014). *Dominion Awarded \$47 Million by DOE for Offshore Wind Turbine Demonstration Project* [press release]. Retrieved from <http://dom.mediaroom.com/2014-05-07-Dominion-Awarded-47-Million-by-DOE-for-Offshore-Wind-Turbine-Demonstration-Project>.

emergence of the Commonwealth Energy Fund (CEF) in 2011 sponsored by DMME and the DOE as well as the precursor Technology Acceleration Program (TAP) Fund signal both the availability of high impact, R&D stage technologies combined with targeted equity designed to drive start-ups toward broader commercial uses.



Energy R&D at Virginia Colleges and Universities

Table 10-1 highlights the energy-related R&D performed by Virginia institutions of higher education, and demonstrates the breadth of research and potential synergies among the organizations.



Research areas with current or potential national prominence include:

- Carbon sequestration
- Advanced separation technologies
- Nuclear power
- Fuel cells and hydrogen
- Biofuels
- Electric grid
- High-power electronics
- Wind
- Energy storage
- Energy efficiency, environment, and conservation
- “Green” building design
- Solar / photovoltaics
- Energy policy

Virginia Tech. The most comprehensive portfolio of energy-related research is found at VT, which supports research activities in every energy area defined in this chapter. Since 2006, VT has identified energy and sustainability research as one of four strategic focus areas within its long range plan, in recognition of the strength and breadth of faculty research in related areas. In that year, the university deans and the Office of the Vice President for Research, created the Virginia Tech Deans' Task Force for Energy Security and Sustainability in an effort to coordinate, promote, and position VT's educational, research, and outreach efforts to achieve sustainable and secure energy systems. Tracking of energy-related research growth began university-wide in 2007. In FY2013, Virginia Tech's energy-related research expenditures, excluding energy-related transportation research, totaled more than \$55 million, an increase of more than 62 percent since FY2007. As of 2014, five VT faculty performing energy-related research have been inducted into the prestigious National Academy of Engineering⁹.

University of Virginia. At UVa, the Energy Systems Prototyping, Research, Innovation and Translation (ESPRIT) program is a priority initiative within the Office of the Vice President for Research. UVa is coordinating its ESPRIT initiative through a faculty steering committee comprised of representatives from its Schools of Architecture, Business, Education, Engineering, Law, and Arts and Sciences. In the broader view, UVa considers the areas of energy, conservation, and environmental sustainability as closely coupled and is striving for a balanced program of research and education.

College of William & Mary. Energy is also prominent at W&M. For example, the Commonwealth Center for Energy and Environment (CCEE) was formed by mandate of the Board of Visitors and is an integral part of the current strategic plan. The CCEE supports initiation grants for the development of strong interdisciplinary approaches to the scientific, social, economic, and political challenges of new and emerging energy-related technologies and environmental challenges. One target of the development group of the College is to promote endowment-funding for centers, to ensure consistent, ongoing support required for success in long-term endeavors like alternative energy.

George Mason University. At Mason, nearly 40 scientists are involved in climate change research and see direct spillover effects on energy. Climate change research has been a strong

⁹ Virginia Tech. (2014). *2014 Virginia Energy Plan: Virginia Tech Inputs*.

component of Mason's College of Science for ten years, with work that has yielded climate change studies for a number of nation states around the world.

Virginia Commonwealth University. VCU is engaged in a comprehensive portfolio of energy research and education activities. With nearly 30 researchers engaged in interdisciplinary projects, VCU's areas of strength include energy generation (renewable energy sources, nuclear energy), energy distribution and storage, energy conservation (green technologies, energy efficiency), environmental impact, and energy policy and education. VCU's portfolio includes more than \$10.7 million in sponsored awards to the university to support energy research and education, with funding from the DOE accounting for over \$5 million.

Old Dominion University. ODU's energy R&D expertise has focused on biomass / algae, photovoltaics, and coastal and environmental research, including wind and wave energy. The Commonwealth assigned ODU the leadership role in the Virginia Coastal Energy Research Consortium (VCERC), with the mission to seek out and develop new alternative energy research directions and evaluate renewable energy sources including algal biomass, wind, and wave resources available in Virginia. VCERC is composed of ODU, HU, JMU, W&M, NSU, VCU, UVA, and VT, as well as government and industry partners.

According to the DOE, wave energy has the potential to power over 100 million homes annually. To realize this potential, **Columbia Power Technologies** (Charlottesville) is delivering a floating, offshore wave energy solution that is scalable in a range of wave conditions.

Although energy R&D is pervasive and among several institution's priorities, academia's energy-related R&D expenditures and obligations cannot be verified and tracked with current data sources. NSF, the source of data for R&D expenditures at colleges and universities does not include "energy" among the fields it tracks in its annual survey of higher education research and development (HERD). Instead, energy R&D is captured under other disciplines, including computer sciences, environmental sciences, life sciences, physical

sciences, and social sciences. Since universities track data that aligns with NSF and other requirements, they typically do not measure energy R&D expenditures or obligations.

Key energy-related research activities and expertise at Virginia colleges and universities are discussed in the following sections, organized by research category.

Energy Generation and Sources

Fossil Fuels

Among its fossil fuel research, Virginia has two nationally-recognized research centers in the area of coal and energy research, as well as advanced separation technologies.

Virginia Tech. Two VT centers are nationally prominent in coal-related research: the Virginia Center for Coal and Energy Research (VCCER) and the Center for Advanced Separation Technologies (CAST). VCCER was created by the Virginia General Assembly in 1977 as an interdisciplinary study, research, information, and resource facility for the Commonwealth and has become one of the nation's leading interdisciplinary energy and environmental research centers. It has a array of high profile R&D programs in areas such as carbon sequestration, coal-bed methane and shale gas production, uranium fuel resource development, international

energy development, mining and reclamation environmental science, sustainable power generation, and energy information management.

VCCER has developed a strong reputation in the field of carbon capture and storage (CCS). Competencies include technical, financial, legal, and planning disciplines of CCS and unconventional natural gas development. A particular area of expertise is monitoring, verification, and accounting (MVA). Other areas include modeling, reservoir characterization, environmental testing, and methane storage mechanisms. As a part of the Southeast Regional Carbon Sequestration Partnership (SECARB) and, under funding via DOE's National Energy Technology Laboratory (NETL), VCCER coordinates all coal seam-related sequestration activities for the SECARB partnership.

VT received \$11.5 million from DOE to implement a pilot project in Central Appalachia. This four-year project is part of a portfolio of projects aimed to better understand the effect of CO₂ on geologic formations. The objective of this project is to design and implement characterization, injection, and monitoring activities of approximately 20,000 metric tons of CO₂ into unconventional (coal or organic shale) geologic formations in Central Appalachia. VCCER also is managing a project to test the injectivity of CO₂ into unmineable coal seams and the potential for enhanced coal bed methane (ECBM) recovery by stressing the coals under injection into three legacy coal bed methane (CBM) wells for an approximate one-year period. In addition, VCCER has conducted a "huff-n-puff" test on a horizontal shale well. The organic shale research will provide much needed information on organic shale sequestration and enhanced gas recovery (EGR).

Led by VT, CAST is a consortium of five universities, which represent the major coal mining schools in Central Appalachia. The consortium was established in 2001 to develop advanced separation technologies that can be used to produce clean-burning solid fuels in an environmentally acceptable manner. CAST has developed advanced separation technologies now widely used in industry, including the Microcel flotation column, hyperbaric centrifuge, and dewatering aids. Its facilities at VT can test new separation processes developed at the Center at proof-of-concept and pilot-scale.

CAST Director, Dr. Roe-Hoan Yoon, has commercialized a number of technologies including techniques to recover coal from slurry ponds as well as a hydrophobic-hydrophilic separation (HHS) process that can produce super-clean coal, recover critical materials from unconventional resources, and clean up the environment.

VT's R&D in fossil fuels extends to mine de-gasification design, groundwater monitoring and modeling, and seismic monitoring and interpretation.

VT departments also are active in energy minerals, including the environmental impacts of the production and use of energy minerals and minerals exploration, extraction, and processing. VT's Department of Mining and Minerals Engineering is the largest such program in North America and has a strong international reputation for its academic, research, and public service programs.

University of Virginia. UVA's DOE-funded Energy Frontiers Research Center (EFRC), the Center for Catalytic Hydrocarbon Functionalization (CCHF), is led by Director Brent Gunnoe. The mission of this Center, which includes leading institutes from across the U.S., is to develop homogeneous catalysts and highly efficient catalytic processes for natural gas, methane, and

other fuels, as well as feedstock chemicals. This effort is a key element of the current initiative to create the joint Max Planck Society-UVA laboratory on new chemical energy processes.

Additionally, other Virginia colleges and universities, including Mason, GWU, HU, ODU, VMI, and W&M are performing R&D to advance fossil fuels technology and policy.

Nuclear

Virginia continues to have a strong nuclear R&D foundation as evidenced by the scale of research investigations identified and educational programs offered.

The Virginia Nuclear Energy Consortium Authority (VNECA) was established to position Virginia as a national and global leader in nuclear energy and to serve as an interdisciplinary study, research, and information resource for the Commonwealth on nuclear energy issues. Established in the 2013 Session of the General Assembly, VNECA members include educational institutions, Virginia-based federal research laboratories, nuclear-related nonprofit organizations, and business entities.

Virginia Commonwealth University. As a founding member of the VNECA, VCU's sponsored programming activities contribute to "making the Commonwealth a national and global leader in nuclear energy and serving as an interdisciplinary study, research, and information resource for the Commonwealth on nuclear energy issues."¹⁰ Major efforts are currently funded by a number of agencies, including the Nuclear Regulatory Commission (NRC), NSF, and DOE.

Several noteworthy research projects are underway at VCU's Department of Mechanical and Nuclear Engineering, including applied research for nuclear power plant safety, such as thermal-hydraulics modeling and simulation of event scenarios and nuclear systems for existing and advanced nuclear reactor designs conducted by Dr. Sama Bilbao y León.

Dr. Supathorn Phongikaroon is advancing and developing materials accountability and detection techniques for used nuclear fuel in reprocessing technologies and developing advanced fuel cladding materials for existing light water nuclear reactors for safer, accident-resistant nuclear fuels. Additionally, Dr. James Miller is designing and constructing a small electrostatic inertial confinement fusion reactor to be used for fundamental nuclear fusion research, a gamma radiation and neutron flux source for teaching and research applications, and designing and implementing a full-scale nuclear plant simulator that may be used for education and outreach. The latter project opens new applications for nuclear safety and design.

University of Virginia. UVa maintains faculty expertise – Drs. John Scully, Rob Kelly, and Glenn Stoner – in nuclear containment systems based on amorphous materials resistant to corrosion, although the two nuclear reactors at the university were decommissioned (in 1988 and 1998) and the program ceased in 1999¹¹. The university's Center for Safety-Critical Systems includes a virtual nuclear reactor control room located at the Center for Advanced Engineering Research (CAER) in Lynchburg. The Lynchburg control room, established in conjunction with AREVA and Babcock & Wilcox, is utilized for education and training of nuclear reactor control room personnel into safe operations of nuclear reactors.

¹⁰ Va. Code Ann. § 67-1400 (2013).

¹¹ P. Parrish, personal communication, September 22, 2006.

UVA's Dr. Hornberger was named to the U.S. Nuclear Waste Technical Review Board by President Bush in 2004. The board provides independent scientific and technical oversight of the U.S. program for management and disposal of spent nuclear fuel from civilian nuclear power plants¹².

College of William & Mary. W&M is active in R&D for nuclear energy, including in the areas of high heat flux and corrosion resistant materials. W&M has a particular interest in materials for small modular reactors (SMRs) and is developing proposals for R&D related to these materials in SMR shipboard use.

George Mason University. Mason's Dr. Roger Stough had a significant role in designing the KEPCO International Nuclear Graduate School (KINGS), Korea's leading nuclear power training program for export markets. The program was launched with a focus on education and training; the R&D program is under development, with a Korean R&D expert planning to stay at Mason's campus for the next year to participate in the design of the research program¹³.

Virginia Tech. VT also is engaged in nuclear energy-related R&D. Its Nuclear Engineering Program (NEP) in the Department of Mechanical Engineering has expanded over the past six years via new and affiliate faculty bringing expertise in the areas of: (1) particle transport methods and their applications (reactor physics and shielding, nuclear safeguards and security, radiation diagnostics); (2) reactor operations and instrumentations; (3) nuclear materials; (4) plasma physics and fusion; and (5) reactor thermal hydraulics and safety. In support of their research activities new laboratories include: (1) Radiation Measurement, Simulation and Visualization (RMSV); (2) Multiphase Flow and Reactor Thermal Hydraulics (MURETH); and (3) Ionized Species for Innovative Science (IS2). The Nuclear Science and Engineering Lab (NSEL) extends the NEP to the National Capital Region.

VT's Experimental Nuclear and Particle Physics group is involved in experiments that explore the nature of the fundamental building blocks of the universe and seek to measure their properties as precisely and accurately as possible. Additionally, the Microwave Processing Research Facility in the Department of Materials Science and Engineering VT is examining new ways to expand the use of nuclear energy while minimizing the risks to the public. In addition to the efficiency of the processing method being studied, the approach would use stockpiles of what is now considered radioactive waste in an energy-producing application.

Nuclear seismic safety is another area of research at VT, with expertise in such topics as performance-based design of nuclear facilities; wave and tsunami modeling, coastal erosion, and associated probability and risk assessment; seismic hazard analysis, soil structure interaction, and analysis of soil-related hazards such as liquefaction and slope stability; novel materials, such as ultra-high performance concrete, steel, glass and carbon fiber composites; seismic engineering; and structural health monitoring and diagnosis.

Fuel Cells / Hydrogen

There is a diverse array of research in fuel cells and hydrogen-related technologies with manifold applications such as transportation, buildings, and storage.

Virginia universities have significant research strength in the area of fuel cells and hydrogen.

¹² University of Virginia. (2014). *Assessment of Energy-Related Research and Development in Virginia*.

¹³ "Energy". *George Mason University: Center for Infrastructure Protection & Homeland Security*. 2014. Retrieved from: <http://cip.gmu.edu/programs/energy/>.

Virginia Commonwealth University. Professor Puru Jena leads research aimed at finding materials that are light, cost-effective, safe, and can store a large amount of hydrogen so that a car can have a driving range of 300 miles. The VCU team is among the world leaders in providing the fundamental understanding of these hydrogen storage materials and designing novel nanomaterials and catalysts to improve performance. Their theory of trapping hydrogen in molecular form is guiding world-wide research; several laboratories around the world are trying to synthesize novel storage materials designed at VCU. Additionally, the research team of Drs. Hani El-Kaderi and Samy El-Shall is working on developing metallic and bimetallic nanostructures encapsulated within highly porous coordination polymers (nanopores) for efficient storage of hydrogen.

Virginia Tech. At the Advanced Research Institute (ARI), Dr. Saifur Rahman and Mr. George Hagerman conducted a survey of technologies for producing, transporting, storing, and using hydrogen and compiled the findings into short overviews and fact sheets for use by the general public.

VT has a cluster of researchers focused on improving fuel cell performance, including fuel cell durability / sealants, composite systems, durability modeling, the integration and performance analysis of fuel cells in systems such as buildings and automobiles as well as for stationary (residential) power plan applications. A number of centers are engaged in the research, including the Center for Automotive Fuel Cell Systems, Center for Energy Systems Research (CESR), and the Future Energy Electronics Center (FEEC), and the Institute for Critical Technology and Applied Science (ICTAS). ICTAS has a strong focus on electrochemical energy and storage within its larger thrust area of sustainable energy.

A research team led by Dr. Percival Zhang has developed a battery that runs on sugar and has an unmatched energy density, a development that could replace conventional batteries with ones that are cheaper, refillable, and biodegradable. While other sugar batteries have been developed, Dr. Zhang said his has an energy density an order of magnitude higher than others, allowing it to run longer before needing to be refueled¹⁴.

University of Virginia. Several researchers are focused in the non-hydrogen fuel cell arena. Dr. Elizabeth Opila is working to develop high-performance anode materials for versatile high-temperature solid oxide fuel cells that can use a variety of combustible fuels including gasoline and biodiesel to produce both heat and electricity while minimizing carbon release. On a more fundamental level, research is underway to optimize catalytic materials for yield, selectivity, or minimized energy use. A specific focus is on the reactivity of methane, which, with the right catalysts and conditions, could potentially be harnessed at the well-head as a reliable source of easily transportable methanol for powering fuel cells.

James Madison University. Drs. Samuel Morton III and Bradley Striebig are working on the development of microbial fuel-cells (MFC) designed to produce low-level power from carbohydrate rich waste streams. The potential to produce power directly from aqueous waste streams is significant, and the work at JMU has focused on developing low-cost, feedstock agnostic MFC systems for use at smaller scale facilities, where other waste stream conversion systems are not economically viable.

¹⁴ Virginia Tech. (2014). *2014 Virginia Energy Plan: Virginia Tech Inputs*.

George Mason University. As part of Mason's global climate change research, fuel cell technology is viewed as a scalable way to help offset the impact of the build-up of CO₂. Mason's multi-faceted fuel cell research includes that in microbial fuel cells and that based on nano porous materials.

Biofuels

There is demonstrable institutional expertise and critical mass with feedstock R&D across the State.

Virginia Commonwealth University. Professor Stephen Fong is leading research aimed at developing efficient processes that can produce large quantities of biofuel. Specific projects underway in 2014 include turning biomass into usable sugar, for which a patent is being filed; using novel microorganisms to convert cellulose into butanol; and computational modeling of organisms to predict genetic engineering designs.

Other research at VCU deals with the development of biofuels from algae, including determining the oil content of naturally occurring algae in water bodies of the Commonwealth of Virginia to assess their utility for biofuel production. In collaboration with ODU, VCU is developing technology related to biomass production and oil extraction.

The potential upside for the biomass industry in Virginia is enormous. **Piedmont Bioproducts** (Gretna) is one of many firms offering unique renewable energy solutions. Piedmont's process involves generating bio-crude from feedstock utilizing a thermal-chemical refining process.

Institute for Advanced Learning and Research. At the IALR, biomass to cellulosic ethanol and biodiesel energy generation are important areas of research. From development of mutagenic processes to improve yields, cold or heat tolerance, or other trait enhancements for various bioenergy feedstocks to commercial processing options using various chemistries, IALR's researchers, along with its commercial and academic partners, are driving toward identifying an optimal directed-energy feedstock for the mid-Atlantic region while examining the environmental and economic impacts, positive and negative, on all research endeavors.

Dr. Yinghui Dan is researching and developing trait improvements and a high-throughput micropropagation system around a promising bioenergy crop, *Arundo donax L.*, due to its perennial nature and high levels of biomass production. Drs. Barry Flinn, Chuanshang Mei, Scott Lowman, and others have published results from studies around a promising bioenergy crop candidate, switchgrass. Through the use of microbial endophytes, IALR has helped improve switchgrass performance by developing a low input, sustainable production system. The endophyte-inoculated, tissue-cultured switchgrass plants grow bigger and are designed to require less water and fertilizer than control plants. Critical to the success of these two crops is the work on a third, *Miscanthus x giganteus*; Drs. Kedong Da and Song Zhang provide world-class tissue culture expertise in IALR's study of these bioenergy generation sources, as high-volume breeding will be necessary to launch the production of such crops.

Old Dominion University. Dr. Sandeep Kumar's laboratory is collaborating with Tyton BioSciences of Danville, VA to develop sugar extraction technology from tobacco feedstock for biofuels production. Their research aims to prove the feasibility of an integrative approach of applying subcritical water extraction methods to enhanced tobacco varieties for the economic production of sugars and oils for bioethanol and biodiesel manufacturing.

Virginia Tech. VT's efforts include issues ranging from biomass production, to deconstruction and conversion technologies, along with significant expertise in environmental impacts, community viability, and numerous enabling technologies ranging from computational support and genomics to engineering process technology, business development, and land use policies. Additionally, VT is collaborating with bioenergy crop developers and many other universities in a large project that aims to deliver highly productive crops with minimal risk of escaping cultivation and becoming harmful invasive pests.

Scientists in the laboratory of Dr. Bingyu Zhao are working on improving the characteristics of the feedstock switchgrass, which is considered a prime candidate for large-scale biomass production for ligno-cellulose derived bioenergy. VT researchers Dr. Eric Beers and Dr. Amy Brunner are looking at poplar as a feedstock source, while researchers in the laboratory of Dr. Ryan Senger are looking for ways to overcome the recalcitrance of cellulosic materials through biological conversion. Dr. Jactone Ogejo and others are investigating biogas options for dairies in Virginia, specifically the use of anaerobic digestion to produce biogas from manure.

Dr. Percival Zhang has developed a gentle and cost-effective pretreatment process for biomass. The weakened biomass can be fractionated into four products: lignin, acetic acid, hemicellulose sugars, and amorphous cellulose. This technology has been licensed by Biomethods. Dr. Zhang has also developed another energy product from biomass sugars – hydrogen to power a fuel cell. His aim is to have the conversion occur in a car's fuel tank or at a fuel cell site.

Virginia Military Institute. At VMI, research is underway to develop a soybean cultivar for use as an alternative fuel source and test the cultivars for their energy and emissions potential. Additional research is in biochar production for use in water treatment and to test various blends of biodiesel fuels for their performance in diesel combustion engines.

College of William & Mary. W&M has programs underway to develop large-scale algae biomass for non-ethanol transportation fuels, or for environmental remediation of water contamination associated with fossil fuel and natural gas production.

James Madison University. A primary focus of JMU's Alternative Fuel Vehicle Laboratory is R&D of a novel algae-oil harvesting strategy developed by Dr. Chris Bachmann for the production of biofuels. This harvesting strategy is the result of algae-based biofuels research that began at JMU in 2005.

Nearly all of the algae harvesting strategies developed to-date involve dewatering and drying the algae prior to extracting valuable components. These drying steps are both energy intensive and expensive. In August 2012, researchers applied a commercially available device to successfully extract oil from salt-water algae without removing them from the seawater culture media. Test results indicated that the strategy was, in fact, capable of isolating lipids including high-value co-products and pharmaceuticals from algae without removing them from sea-water. A provisional patent application has been filed by James Madison Innovations, Inc.

Other areas of research include biodiesel production on the development of a small-scale, portable continuous flow system for producing biodiesel from waste oil at the point of generation and a multi-pronged approach to generation of biofuels and bioproducts from the lignin-fraction of lignocellulosic biomass.

University of Virginia. UVa has a number of research efforts to convert biomass into fuels, chemicals, and feedstocks for pharmaceuticals. These efforts are led by Dr. Robert Davis. Research includes deriving butanol from biomass-based ethanol, as butanol has higher energy content as a fuel than does ethanol and is a feedstock to produce a number of chemicals and pharmaceutical products, and transforming biomass from farm crops to advanced fuels and chemicals. The latter research is performed through the NSF Engineering Research Center, Center for Biorenewable Chemicals (CBiRC), led by Iowa State.

Norfolk State University. NSU is developing a research effort in renewable energy solutions and applications; many of the renewable energy sources are currently disposed of as waste. Each of the effort's four major thrusts constitutes a portion of an interconnected bio-energy manufacturing process: (1) bio-diesel from grains resulting in glycerol production; (2) production of bio-jet fuel; (3) waste oil to bio-diesel and glycerol; and (4) other marketable manufacturing process by-products.

Waste-to-Energy

James Madison University. Dr. Adebayo Ogundipe is developing an assessment tool to be used in comparative analyses to determine the sustainability potential of various alternatives for poultry litter disposal, particularly poultry litter to energy technologies. This research is important to the Commonwealth, as poultry production results in massive amounts of litter that are applied to pastures and hay meadows and can lead to an excessive accumulation of nitrogen and phosphorus in soil and bodies of water. Dr. Ogundipe's Sustainability Assessment Matrix (SAM) allows for the comparison of overall systems and guides decision-making within subsystems. Additionally, research is being performed on biochar, a soil amendment / energy source that was first utilized more than 3,000 years ago. In this regard, Dr. Wayne Teel oversees projects involving the construction of biochar chambers, which are installed on Shenandoah Valley farms to produce heat for greenhouses as well as a fertilizer that reduces loss of nutrients in the field, promotes local nutrient cycles, and sequesters carbon.

Old Dominion University. Dr. Sandeep Kumar's laboratory at ODU is working with Fiberight, LLC in Lawrenceville, VA to develop innovative solutions to convert trash, otherwise destined for disposal, into a renewable fuel and energy. The process is aimed at converting municipal solid waste (MSW) into cellulosic biofuel and marketable electricity in a cost-effective and efficient manner.

Faculty in the Colleges of Sciences and Engineering are researching novel methods of producing biochar from waste biomass. The technology is directed at different biochar chemical compositions containing partially oxygenated materials with higher cation exchange capacity for soil amendment, water cleaning, and carbon sequestration. The goal of the project is to develop advanced biochars as a strategy to retain soil water and enhance environmental water quality.

Geothermal

Virginia Tech. VT Geological Sciences performs geothermal energy research. It developed the southeastern United States Geothermal Database website, hosting data on terrestrial heat flow, practical applications of low temperature geothermal energy, and a temperature vs. depth database for those wanting to do their own calculations to evaluate hypotheses of global warming using a geothermal approach to climate reconstruction. This site is frequently updated

to include temperature data, rock thermal conductivity, and heat flow values from New Jersey to Georgia¹⁵.

Water / Hydroelectric Power

Virginia Tech. Dr. Donald Orth (College of Natural Resources and Environment) noted that faculty members in the College have expertise in river and reservoir water quality, fish protection, and screening at hydropower plants, population viability analysis, and environmental analysis of the costs and benefits of alternative operation regimes. These skills are essential to the process of licensing new hydropower facilities as well as the rehabilitation and upgrade of existing facilities¹⁶.

Solar / Photovoltaics

Old Dominion University. ODU established the Virginia Institute of PhotoVoltaics (VIPV) in 2013 under the direction of Dr. Sylvain Marsillac. Research interests include fabricating the next generation of highly efficient and cost-effective thin film solar cells, developing innovative tools for in-situ and real-time analysis, and engineering new systems for large area photovoltaic installations. The university's research focus on photovoltaic energy expanded to include partnering with Dominion Power to install more than 600 solar panels in 2013 and 2014 on the roof of the Student Recreation and Wellness Center in the heart of the campus. The panels will generate kilowatt power for the electric grid with enough energy to power about 31 homes and tie in to the photovoltaic research laboratory.

Norfolk State University. Dr. Sam-Shajing Sun is a recognized leader in polymer materials research for solar cell applications. Dr. Sun's research expertise includes the design, synthesis, processing, characterization, and modeling of novel organic and polymeric solid state supra-molecular and nanostructured materials and thin films devices for electronic, photonic, magnetic, and energy conversion applications. Current research projects funded by the DOE and the Army Research Office (ARO) include development of photovoltaic polymers and thermoelectric polymers.

George Mason University. Dr. Jessica Lin is applying computer science and data mining techniques to advance efficiencies in solar power technology.

Virginia Commonwealth University. Professors Hadis Morkoc and Umit Ozur are developing a new class of solar cells beyond the silicon technology (~20 percent efficiency for single crystal Si) through multiple electron hole generation for >50 percent efficiency using stacked InAs quantum dots. Their pioneering research involves high brightness and longevity (>10 years) LEDs to replace the current incandescent (efficiency improvement of 10x) and fluorescent light (efficiency improvement of 3x) bulbs while avoiding the harmful mercury endemic to fluorescent light bulbs and reducing carbon emission¹⁷.

A research team led by Dr. James McLeskey, Jr. is working on polymers for solar photovoltaic power that can be manufactured at very low cost. The polymer-based solar cells investigated involve nanomaterials such as carbon nanotubes that can be aligned through an electric field for improved efficiency. These researchers were the first to report the fabrication of polymer

¹⁵ "NGDS: National Geothermal Data System". *Virginia Tech*. <http://www.geothermal.geos.vt.edu/>.

¹⁶ Virginia Tech. (2014). *2014 Virginia Energy Plan: Virginia Tech Inputs*.

¹⁷ Virginia Commonwealth University. (2014). *VCU Energy Research_June 2014_FINAL*.

photovoltaics using a water-soluble polythiophene polymer known as PTEBS¹⁸. While most polymers will dissolve only in highly toxic solvents, water solubility offers the advantage of environmentally friendly processing – an important consideration for “green” technology.

Professor M. Samy El-Shall is collaborating on research to develop efficient photovoltaic cells based on chemically modified titanium dioxide and highly ordered CdSe quantum dots. Utilizing both CdSe quantum dots and nanorods with mesoporous titanium dioxide, the project is developing nanomaterial photovoltaic devices and evaluating their performance in ambient air conditions at room temperature. Dr. El-Shall also is developing nanomaterials that can serve as catalysts in petrochemical and environmental applications.

Virginia Tech. Dr. Ranga Pitchumani is a leading expert in the field of concentrating solar power. He and his research group at VT have developed novel thermal energy storage technologies for concentrating solar power applications that are widely published. For example, Dr. Pitchumani was invited to direct his Concentrating Solar Power (CSP) program for the 2011 DOE SunShot Initiative, a program to reduce the installed cost of solar energy systems by about 75 percent in order to allow widespread, large-scale adoption of this renewable clean energy technology. Under his leadership, the CSP has launched over \$130 million in new funding initiatives since October 2011 dedicated to applied scientific research, development and demonstration to advance cutting-edge concentrating solar power technologies for the near-, mid- and long-terms.

Professor Karen Brewer and her group have been developing molecular devices for the photoinitiated collection of electrons and the production of hydrogen from sunlight. Professor Brewer’s most recent research involves a system for the light-driven production of hydrogen from water.

Additional research includes that of the Amanda Morris Group of Inorganic and Energy Chemistry, which focuses on two aspects of solar energy conversion: artificial photosynthetic assemblies, assemblies that can oxidize water and reduce CO₂ efficiently to a solar fuel cell, and next-generation solar cells, where the focus is on two types of cell architecture – hybrid bulk heterojunction and quantum dot synthesized. The latter proves its importance as the 2010 cost of a residential photovoltaic system was more than four times the 2020 DOE goal; the dramatic and quick cost reduction required to reach this goal necessitates the development and demonstration of revolutionary photovoltaic technology.

VT models the integration of renewable sources such as solar photovoltaic generators with probability models of solar irradiance at various geographic locations in Southern California and Nevada. These models were used to improve the reliability of unit commitment of solar energy by a group of solar installations that are geographically distributed.

James Madison University. JMU Engineering faculty Dr. Jacquelyn Nagel, is exploring the technical challenge of sustainability as it relates to solar energy production, storage, and consumption. The two-phase energy system project aims to reduce chemical battery waste by providing electrical energy during both day and night without the use of chemical batteries and correlates to a reduction in pollutants at three points in the system’s lifecycle: (1) less fossil fuel burned at a power plant; (2) less chemical waste created due to battery manufacturing, consumption and recycling; and (3) greater recycling potential.

¹⁸ Q. Qiao and J.T. McLeskey, Jr., “Water-soluble polythiophene / nanocrystalline TiO₂ solar cells”, Applied Physics Letters, Vol. 86, p. 153501, 2005.

Other Virginia universities are also focused on this area of energy-related research. Several UVa faculty, including Drs. Mool Gupta, Petra Reinke, and Joe Campbell are involved with photovoltaic materials and / or solar energy. At VMI, Drs. Daren Timmons, Daniela Topasna, and Gregory Topasna are among faculty involved in research that includes developing photovoltaic cells and thin films to improve their performance and to produce chemical coatings for more efficient solar panels.

Wind

Virginia Tech. Wind energy expertise and activities cover a broad range of technical areas and policy. On the technical side this includes programs in computational and experimental aerodynamics, aeroacoustics, acoustics, structures, materials, and ocean systems, centered at the Blacksburg campus. On the policy side, work is centered at the ARI in Arlington, Virginia.

Anchoring a substantial portion of the technical activities is the VT Stability Wind Tunnel. This internationally recognized facility is a major asset to the university and to the Commonwealth in many areas of aerodynamic and aeroacoustic testing, but particularly in wind energy. It produces an extremely high quality air-flow for testing at speeds of up to 190 mph and is one of the largest university-owned wind tunnels in the U.S. The key technical advance that has given this facility international visibility and placed it at the forefront of aeroacoustic and aerodynamic wind energy research is the invention at VT in 2005 of the hybrid anechoic test section (HATS)¹⁹, a technology in which tensioned Kevlar cloth is used to guide the air flow over models, while allowing the sound produced to pass out of the flow and be accurately measured. The tunnel is the only accessible facility worldwide where wind turbine blade aeroacoustics and aerodynamics can be measured at, or near, full scale conditions. Additionally, under development are systems for infrared transition detection, global optical boundary layer measurement, and stereoscopic camera system for boundary condition definition.

A new area of aerodynamic and acoustic research is understanding what is required to fabricate wind turbine blades using fabric stretched across a frame, in place of the conventional fiberglass construction. This promises a substantial reduction in wind energy cost. A companion to VT's wind energy efforts is research in the science of aerodynamic testing itself, including efforts in instrumentation development, wind tunnel corrections, and in relating wind tunnel tests to computational simulations.

Accompanying the experimental wind turbine aerodynamics are programs and capabilities in aerodynamic simulation and modeling. VT Aerospace and Ocean Engineering (AOE) faculty and students are collaborators on a DOE-funded research project to develop a cyber wind facility, which is a wind turbine-level (vs. farm-level) simulation suite of tools for generating highly-resolved 4D cyber data. This data can be used to perform virtual full-scale experimental campaigns, support design of systems and experiments, improve actuator-line models and other design-level tools, and evaluate control systems. The long-term vision is the creation of a cyber facility for wind turbines to advance wind farm siting and design, and wind turbine / farm controls to simultaneously maximize production and increase turbine reliability.

VT faculty have diverse expertise in the modeling, analysis, and testing of structures and materials. This broad area of expertise includes the (a) analysis, optimization, and fabrication of composite airfoils; (b) multi-scale, multi-disciplinary analysis and design of wind turbine blades

¹⁹ "Center for Energy and the Global Environment". Virginia Tech. Retrieved from: <http://www.ceage.vt.edu/home>.

with focus on aeromechanics and aeroelasticity of rotating systems; (c) damage detection, diagnostics, and failure prediction in composite structures; (d) multi-scale modeling and characterization of multi-functional nanomaterials; (e) dynamic analysis and testing of bladed structures; and (f) analysis and optimization of morphing structures for airfoils and related control surfaces.

VT has a cluster of faculty members in the AOE and Civil and Environmental Engineering (CEE)

In May 2014, **Dominion Virginia Power** (Richmond) and partners were awarded \$47 million in continued funding from DOE to fund the construction of a 12-megawatt offshore wind demonstration project. The demonstration is intended to showcase the ability of two 6-megawatt wind turbines to power 3,000 homes by 2017.

departments with research expertise in coastal systems. Research focuses on wave-seabed interactions, sediment transport, and on the impact and risk assessment of coastal hazards and climate change. Experience and capabilities include large-scale experimental investigations and advanced numerical model development for the failure potential and mechanism of foundations under extreme coastal loadings during tsunamis and storm surges. Understanding the failure potential of the turbine components, their supporting structures, and the

seabed foundations is critical for assessing the uncertainty in the feasibility study phase and in selecting appropriate plans in the preliminary design phase.

The ARI is also engaged in policy and planning work to support offshore wind. The work includes support to DMME for lease applications to the U.S. Bureau of Ocean Energy Management (BOEM), DMME responses to BOEM sale notice for the commercial wind energy area, and a DMME-BOEM offshore regional geological study and ocean survey. This work also includes support for Virginia engagement with the DOE Chesapeake Light Tower initiative, Virginia offshore wind supply chain acceleration white papers, and Virginia Offshore Wind Development Authority briefings. In addition VT-ARI is supporting the Virginia Offshore Wind Technology Advancement Project (VOWTAP) five-year demonstration project.

James Madison University. Efforts began in 1999 at JMU to characterize the wind resource on land throughout the Commonwealth, and to promote stakeholder engagement within various sectors. JMU joined with ODU and other academic and business interests in 2006 to form the Virginia Coastal Energy Research Consortium (VCERC), and in 2009 the VCERC board recognized the JMU wind research team as the Virginia Center for Wind Energy (CWE) at JMU. Led by Professor Jonathan Miles, the CWE performs research and provides educational and technical opportunities, support, and resources to foster the advancement of sustainable energy in Virginia particularly to advance wind energy deployment.

The CWE conducts research pertaining to wind resource and siting assessment, primarily in support of small- and community-scale project development. Activities include wind data collection and analysis using conventional meteorological towers as well as SoDAR instruments, and analyses that involve the development and / or manipulation of Geographical Information Systems (GIS) data and assessments of policy, regulatory, and financial considerations. Since 2002, the Center has acquired wind data from several dozen locations throughout Virginia in support of project development by residents and businesses.

In 2011-12, CWE conducted a major study to determine the viability of deploying large offshore wind turbines in state waters. In 2012-13, under contract with the National Renewable Energy Laboratory (NREL), the Center completed two modeling studies that utilized NREL's Jobs and

Economic Development Impact (JEDI) model for offshore wind to project jobs and economic benefits to the Southeastern and Mid-Atlantic regions of the U.S. as offshore wind is deployed through 2030. These studies underscored how Virginia is uniquely positioned, because of its exceptional resources and supply chain opportunities, to capitalize as this industry advances²⁰. The Center expects to engage in further studies to support offshore wind development in Virginia, by addressing remote health monitoring of wind turbine blades and the development of a data repository and viewer to support public access to wind data offshore.

University of Virginia. Dr. Eric Loth is leading a large, multi-institutional research effort on bio-inspired morphing wind turbine blades for offshore wind applications and nanoparticle-containing coatings for the blade. This effort also includes AREVA-sponsored research on nacelles, which are oleophobic and shed water very efficiently. The research led to two patent applications and has the potential to reduce the size and cost of offshore wind turbine systems by 25 percent²¹.

Energy Transmission and Technologies

Energy Grid

Virginia Tech. VT has been a leader in the field of power engineering, with its faculty and students receiving both teaching and research awards. The goal of its Center for Power and Energy is to shape the smart grid into a dependable, sustainable, and robust system. Projects focus on wide area monitoring, adaptive relaying for protection, communication and cyber security as related to power systems, economics of microgrids, and integration of renewables.

The Renewable Energy and Nanogrids (REN) mini-consortium, part of the Center for Power Electronics Systems (CPES) at VT, is developing electronic energy processing technologies for sustainable living environments that satisfy energy, functional, comfort, and zero-CO₂ emission goals. CPES is building a living lab testbed based on AC and DC electric power systems using photovoltaic solar cells, wind generators, micro-turbines, fuel cells, and lithium-ion storage. The testbed will help address many of the nanogrid issues, such as DC bus architecture, energy / power management, and various forms of utility interface converters and inverters.

VT received a \$1.25 million five-year contract in 2009 from DOE to develop, manage, and maintain a public Smart Grid Information Clearinghouse (SGIC) web portal that encourages use of electricity in an environmentally responsible way. Project partners assist with content, which includes demonstration projects, use cases, standards, legislation, policy and regulation, lessons learned and best practices, and advanced topics dealing with R&D. The Smart Grid Clearing House site was launched in September 2010²². Furthermore, as part of a three-year DOE demonstration led by VT, a phasor only – three-phase state estimator – is being installed on the Dominion Virginia Power 500kV system. This technology will advance Dominion's ability to identify potentially damaging conditions and implement corrective and preventative strategies²³.

²⁰ James Madison University. *James Madison University: Energy R&D Info – June 2014*.

²¹ Loth, Eric. "Off-Shore Wind Energy Technologies". University of Virginia, Mechanical and Aerospace Engineering. 7 December 2010. Retrieved from: <http://www.vaallies.org/assets/files/allymeeting/OffshoreWind/10.RichmondWindMeetingLoth.pdf>.

²² Virginia Tech. (2010). *Virginia Tech Officially Launches Smart Grid Information Clearinghouse Web Portal*. [press release]. Retrieved from:

<http://www.vtnews.vt.edu/articles/2010/09/093010-ncr-finalsmartgridportallaunch.html>.

²³ Virginia Tech. (2014). *2014 Virginia Energy Plan: Virginia Tech Inputs*.

Virginia Commonwealth University. Professor Zhifang Wang performs research on energy distribution including smart grids, voltage stability and energy system modeling and optimization.

George Mason University. Mason's Center for Smart Power Grids performs research to move the centralized, producer-controlled electric network to one that is much more distributed and consumer interactive. The Center's twenty-five scientists, many of whom are world authorities in their areas of expertise, concentrate on Smart Grid technology research, development and demonstration, among other areas. Foci include recovery from energy supply disruptions to minimize negative economic impact, optimal enhancement of electric grid infrastructure to make it robust against natural and man-induced disasters, and smart grid interoperability.

Energy Use / Impact and Technologies

Energy Storage

College of William & Mary. Faculty are working on experimental and computational solid state physics and science of such materials, with an interest in solid state energy conversion devices, to include thermoelectrics and pyroelectrics on the one hand, and piezoelectrics and ferroelectrics on the other. Such devices, capturing waste heat from various sources, or capitalizing on motion associated with walking, gesturing, vehicle braking, or other motive power can be useful, including for the military, to supply power for field-portable devices, long-duration surveillance, autonomous underwater vehicles, or other applications.

Virginia Commonwealth University. Professors Puru Jena and Hani El-Kaderi and their research teams are collaborating to develop the next generation of Li-ion batteries that are halogen-free and less sensitive to moisture. Safe and efficient electrostatic storage of energy are keys to address challenges in solar and wind energy which need to be stored for later use.

Professors Max Bertino and Khaled Saoud (VCU, Qatar) are collaborating on a project to explore synthetic methods for aerogels. Aerogels are lightweight porous materials with the lowest known thermal conductivity which provide thermal insulation. They have been underutilized because of their mechanical fragility; by reinforcing aerogels with a polymer using a nanofabrication approach, the team has achieved mechanically stable, strongly insulating composites. Working with the Department of Sculpture at VCU, the Bertino group fabricated molds which will be used to create composites with custom shapes. Investors will be sought to take these to market.

Professor Karla Mossi is developing a hybrid piezoelectric / pyroelectric system to harvest wasted mechanical and thermal energy and convert the wasted energy into a useful energy source.

Other faculty are studying the effect of defects, surfaces, interfaces, and crystal orientation on the electrical and optical properties of GaN and ZnO materials of today's LEDs for low-cost, efficient, and reliable solid state lighting. This research also involves the development of methods for evaluation of absolute optical efficiency of semiconductors and semiconductor.

Additionally, research is underway on reducing defects in LED. The identification of point defects in GaN has immediate relevance to longer life time LEDs.

Researchers in the Quantum Device Laboratory (QDL) are working on replacing the transistor with more energy efficient spin-based devices that can reduce energy dissipation dramatically and lead to energy efficient electronics. Professor Supriyo Bandyopadhyay showed that this device can reduce energy dissipation in electronics by at least 1000-fold, and the QDL has demonstrated extremely stable spin states in an organic molecule, a major step towards the realization of energy efficient green electronics.

With funding from DOE, the research group of Dr. Everett Carpenter is developing energy efficient electric motors. Dr. Carpenter is particularly interested in creating permanent magnets that can match the performance of the best commercial magnets and are less expensive than what is available on the market – without relying on rare earth elements. The goal of this project is to use the magnetic carbide-based composite to develop a magnet for use in a prototype electric motor. According to Dr. Carpenter, the program, if successful, would result in the first commercially viable, rare-earth-free magnet in nearly 50 years.

George Mason University. Mason's Center for Smart Power Grids performs research to move the centralized, producer-controlled electric network to one that is much more distributed and consumer interactive. The Center's 25 scientists, many of whom are world authorities in their areas of expertise, concentrate on smart grid technology research, development, and demonstration, among other areas. Foci include recovery from energy supply disruptions to minimize negative economic impact, optimal enhancement of electric grid infrastructure to make it robust against natural and man-induced disasters, and smart grid interoperability.

University of Virginia. UVa has major strengths and research activities in energy efficiency and conservation. Research is ongoing in the use of microheatpipe technology by Dr. Hossein Haj-Hariri to extract heat from computer chips, a major cause of energy use by air conditioning in data centers across Virginia and the U.S. In Virginia, it is estimated that the total energy usage in data centers costs \$540 million, and that it will grow to \$1 billion in five years, a growth rate of 20 percent. Nationally, this is equivalent to ten new power plants over a five-year timeframe. Extraction of this very high-value heat from data centers to power other systems will greatly diminish the need for air conditioning, which is over 50 percent of the energy cost in data centers today²⁴.

Dr. Kamin Whitehouse has developed a smart control technology for residential and industrial buildings which employs smart sensors and a control system which predicts the occupancy of buildings based upon an algorithm that is developed through tracking of individual occupancy in the building. This is projected to save 30 percent of building energy use²⁵.

²⁴ J.B. Marcinichen, J.A. Olivier, J.R. Thome, "On-chip two-phase cooling of datacenters: cooling system and energy recovery evaluation," *Applied Thermal Engineering*, 41, 36, (2012).

²⁵ "Heating and Cooling Control". University of Virginia. Retrieved from:
<http://www.cs.virginia.edu/~whitehouse/research/thermostats/>.

Virginia Tech. CPES is a \$4 million / year research center dedicated to improving electrical power processing and distribution that impact systems of all sizes – from battery-operated electronics to vehicles to regional and national electrical distribution systems. CPES has a worldwide reputation for its research advances, its work with industry to improve the entire field, and its many talented graduates. From 1998-2008, CPES was a NSF ERC. During the ERC period, CPES developed the Integrated Power Electronics Modules (IPEM), a standardized off-the-shelf module that has revolutionized power electronics. Today, CPES is building on that foundation so that power electronics can fulfill its promise and reduce energy use while helping electronics-based systems grow in capability.

CPES expertise encompasses five technology areas: power conversion technologies and architectures; power electronics components; modeling and control; EMI and power quality; and high density integration, while the Center's targeted applications include: power management for information and communications technology; point-of-load conversion for power supplies; vehicular power conversion systems; and renewable energy systems. The Center is charged with inventing the technology and manufacturing processes for power electronics devices based on wide bandgap semiconductors. CPES will lead the power electronics research and applications thrust.

CPES is also a university partner in the Clean Energy Manufacturing Innovation Institute and will lead the Institute's power electronics research and applications thrust. Led by North Carolina State University, the \$140 million advanced manufacturing institute will receive \$70 million from DOE in the next five years, an amount that will be matched through a combination of funds from the businesses and schools involved, along with at least \$10 million from the state of North Carolina²⁶.

The Power Management Consortium (PMC) aims to develop pre-competitive technologies in power management at the board level. PMC is developing technology for distributed power system architectures, power management, EMI / EMC, power quality, AC-DC converters, DC-DC converters, and POL converters. CPES expects PMC advances to lead to improved microprocessors, netbook, notebook, tablet, desktop, server and networking products, telecom equipment, solid state lighting, and more.

The Center for Energy Harvesting Materials and Systems (CEHMS) under director Dr. Shashank Priya is a consortium of major research universities, industry partners, and commercial and government organizations. It is sponsored through the NSF Industry / University Cooperative Research Centers (I/UCRC) program with the aim of developing integrated solutions for challenging energy efficiency, storage, and distribution problems. At CEHMS, research advances are being made in the fields of materials, structural dynamics, electronics, and storage media to develop self-powered systems, open pathway for distributed power sources and grid integration. CEHMS test beds include energy harvesting solutions for sensors in: extreme environments, intelligent packaging, wearable systems, and implantable systems.

The **Center for Power Electronics Systems (CPES)** at **Virginia Tech** is dedicated to improving electrical power processing and distribution that impact systems of all sizes – from battery-operated electronics to vehicles to regional and national electrical distribution systems. Results are solutions that are more efficient, faster, and use fewer resources.

²⁶ Virginia Tech. (2014). *2014 Virginia Energy Plan: Virginia Tech Inputs*.

Efficiency / Conservation / Environment

College of William & Mary. Approximately 50 people self-identified with environmental research are based on W&M's main campus; a comparable number are based at VIMS. Research includes large-scale database collection on energy operations and other commercial development on habitat, impacts of offshore drilling and wind turbines on migratory birds, and environmental impacts of toxins from hydrocarbon energy on food webs. W&M's well-known experts include Dr. Robert Diaz, the world's foremost authority on marine "dead zones," and Dr. Deborah Bronk, a leading authority on deep-cycle interchange between organic and inorganic oceanic carbon, governing carbon oxide exchanges between the atmosphere and coastal and deep oceanic waters, geologic and biomineral sinks, and active marine life of all types. These areas of interest are directly connected to fossil energy production and refining within the coastal zone, and the generation of petroleum based fertilizers, pesticides and herbicides. In addition, and directly related to climate effects of greenhouse gas production from fossil fuels burning, W&M / VIMS is a world leader in predictive computational modeling of inundation in coastal zones.

Sustainability is a major issue at W&M, including for its undergraduate students. A several year-old program, funded as a Green Fee by students, supports undergraduate and graduate student research projects, larger facilities energy management grants, and education programs and conference opportunities. It also supports joint internship programs with Dining Services in areas such as composting and recycling. In 2011, W&M's undergraduate business program was ranked the best in the country for sustainability, according to the *Bloomberg BusinessWeek* rankings of 14 specialty areas²⁷. In 2014, W&M appointed its first director of sustainability.

George Mason University. Drs. Hakan Aydin and Robert (Bob) Simon of Mason's Computer Science Dept. and the Center for Smart Power Grids are involved in energy-aware computing and networking. This research, which is interdisciplinary, particularly examines energy management and optimization of small, portable consumer-level devices.

Virginia Tech. Since its founding in 1987, researchers at VT's Interdisciplinary Center for Applied Mathematics (ICAM) have worked on the design, optimization, and control of energy efficient buildings, among numerous other challenges. ICAM is a partner in the DOE's Hub on Energy Efficient Buildings (EEB), now known as the Consortium for Building Energy Innovation (CBEI). CBEI develops and demonstrates systems solutions in a real-world regional context for future national deployment. ICAM also is involved in a collaborative project whose goal is to create new computational science tools to enable the design and control of buildings that consume 50 percent less energy while maintaining comfort.

The Virginia Water Research Center, housed at VT, was authorized by the Virginia General Assembly as a state agency in 1982. The Center has been recognized as one of the nation's outstanding water resources programs. Current projects include the effects of cellulosic biofuel production on regional hydrology and assessing the effectiveness of restoration efforts in Central Appalachian coalfield streams. Additional research in water issues related to coal mining is performed by the Appalachian Research Initiative for Environmental Science (ARIES), a program directed by VCCER.

James Madison University. Led by Dr. Christie-Joy Brodrick Hartman, JMU established the Office of Environmental Stewardship and Sustainability (OESS) to coordinate environmental

²⁷ College of William & Mary. *Virginia Energy Plan – R&D Chapter: William & Mary.*

stewardship efforts across campus, advocate for priorities, and challenge all members of the JMU community to think critically about their role in achieving the long-term stewardship of earth. Through the OESS, a diverse group of leaders across the university developed an environmental stewardship action plan for 2011-2015, with three primary goals: (1) minimize materials impact, emissions, toxins, solid waste, and consumption; (2) conserve, steward, and restore natural systems; and, (3) advance environmental literacy and engagement through research, education, and community programs.

Buildings / Construction

James Madison University. Dr. Maria Papadakis conducts research on energy management strategies for conserving energy and mitigating greenhouse gases in university residence halls. She also researches trends in building energy codes and the cost-effectiveness of "beyond code" building energy rating systems such as HERS, Energy Star, zero-energy homes, and passivhaus.

University of Virginia. As noted in Section 2.0, UVa's energy R&D is part of its ESPRIT initiative. UVa's view is that it is important from the outset to include and coordinate research on efficient use, conservation, sustainability issues, and environmental impacts with the development of alternate energy generation technologies.

80 percent of today's building stock will be in use by 2050. Reducing energy use in residential and commercial building will lower GHG emissions. The **University of Virginia's** John Quale is leading an initiative to increase building efficiency, which includes sustainable design, and reduce the environmental impact of construction.

UVa designed and built the first passive standard, affordable house in South Boston, Virginia, with support from the Virginia Tobacco Commission. This effort was led by John Quale, a nationally recognized expert in sustainable building design, as well as experts in landscape and remediation technology and environmental planning and sustainable communities.

Virginia Tech. Areas of expertise in the Department of Building Construction include sustainability and green building, building performance, safety, and 3D and 4D modeling. Students have opportunities to gain industry experience while analyzing various construction elements by utilizing methods of virtual construction to compare the utility of virtual construction management to traditional methods.

In the Computational Research for Energy Systems and Transport (CREST) Laboratory, primary research areas during the last ten years include building energy and efficient energy utilization, alternative energy production, turbulent and reacting multiphase flows, and combustion. The primary applications of research include: building energy, such as for analyses of building codes to ensure construction of energy efficient residential homes; installation of ground-coupled heat pumps; and conditioning air for gasification processes.

Energy Policy

George Mason University. Mason's Center for Energy Science and Policy (CESP) in the School of Policy, Government and International Affairs includes a focus on affordable, reliable, and clean energy from a variety of sources that reflects both market-based decisions and technological innovation. Particular interests include advancing and coupling clean coal

technology with new export markets for Virginia, power grid issues including grid security, and transportation policy as it intersects energy efficiency and conservation. The Center brings together the College of Science and School of Public Policy; funded projects are anticipated beginning in late 2014 or early 2015.

Dr. Alex Brodsky develops decision support, guidance, and optimization models; among others, he supports the energy, power and sustainability sectors. His research includes operational optimization for microgrids and large-scale power generation, transmission and distribution, and planning and investment decision-making for municipalities and companies. Additionally, Ambassador (ret.) Richard Kauzlarich is a member of the National Capital Area Chapter for the U.S. Association for Energy Economics and will supervise research regarding the intersection of the economics of science innovation with energy policy.

Mason researchers performing economic analyses in fuel cells show that fuel cells not only provide renewable energy but also make electric vehicles more affordable.

Virginia Tech. The Center for Energy and the Global Environment (CEAGE), based at ARI, is a research and educational center charged with determining reliable and secure methods of electricity generation and utilization that are compatible with the environment.

Virginia Commonwealth University. VCU's policy work includes interdisciplinary initiatives. For example, Drs. Sama Bilbao y León, Caley Cantrell, and Ken Kahn collaborate on a large, multi-disciplinary, DOE-funded project to select the optimum path for the long-term management of used nuclear fuel. The team takes into account technical, environmental, and economic considerations, as well as the public perception for the chosen solution.

Professor Bilbao y León also conducts studies in energy and environmental policy, with a focus on the optimum use of nuclear power to address climate change concerns and long-term sustainability. Her valuations of the economic, technical, and licensing feasibility of advanced nuclear technologies such as small modular reactors, assessments of long-term energy source availability, reliability and price stability, and valuation of energy resources have often been funded by stakeholders in the nuclear industry.

James Madison University. Through a partnership with JMU, Virginia Clean Cities (VCC) assists stakeholders, legislators, and agencies in the Commonwealth with various state, local, and national legislative efforts leading to the adoption of alternative fuel vehicles. At the federal level, VCC meets annually with congressional leadership on the success of programs and the value of coalition impact on energy, economic, and environmental security in the Commonwealth and U.S. In support of infrastructure development and vehicle conversion efforts, VCC led the Propane Corridor Development Program, which converted 1200 vehicles across 36 fleets to propane. Following a public-private partnership model, JMU, VCC, and Luck Stone worked with the U.S. Environmental Protection Agency (EPA) on the first comprehensive repower program for construction vehicles in the Commonwealth, by taking 11 old vehicles and modifying them with new engines or replacing them with vehicles that met modern emissions standards.

Dr. Rob Alexander is engaged in policy research regarding the extent to which a range of policy tools incentivizing development of biodiesel capacities at the state level incur the desired outcomes. The present study specifically examines political and capacity variables in North Carolina and Virginia to explain why North Carolina demonstrates greater capacity for biodiesel distribution when compared with Virginia. Preliminary results of this comparative case study

indicate that centralized state government support and guaranteed fuel qualities are important variables to add to future explanatory models.

Dr. Maria Papadakis conducts research on the effects of land use planning, law, and regulation on the development of wind energy systems. She also conducts research and outreach on the cost-effectiveness of renewable energy systems for on-farm net metering applications in partnership with Virginia Cooperative Extension, the USDA's Natural Resources and Conservation Service, and Old Dominion Electric Cooperative. She and Dr. Mike Deaton have facilitated industry partnerships on the design and effectiveness of energy appliance rebate programs.

College of William & Mary. W&M's Public Policy Program and Law School address policy matters for a broad range of energy sectors. The public policy program addresses questions related to adopting new energy technologies, such as structuring incentives for contractors to use photovoltaics and LEED (Leadership in Energy and Environmental Design – a program of the U.S. Green Building Council) standards in their buildings. Other policy research covers environmental and social impacts of Virginia offshore energy development. The Law School is engaged in comparative studies of renewable energy policies (wind, solar) in China and the European Union.

The Institute for the Theory and Practice of International Relations comprises several projects, including a \$25 million United States Agency for International Development (USAID) program. The program includes projects to assess developing world energy, environmental problems, food and military security, all of which have an integral relationship to energy economics.

Old Dominion University. Dr. Adrian Gheorghe works on issues related to comparative risk and vulnerability assessment of various energy systems and the impact of such evaluations on energy policy formation, critical energy infrastructures, and their interdependency with other critical systems such as transportation, information and communications, and pipelines. Recent energy policy modeling efforts include those related to resilience analysis and energy security in national and international scenarios. These scenarios have looked at risk analysis for energy systems and operation performance of computer-assisted infrastructures (e.g., SCADA systems) exposed to cyber attacks.

Other Energy Research Projects

College of William & Mary. W&M is active in multiple energy storage projects, including as a subcontractor to the University of Nevada, Las Vegas on a federally-sponsored R&D program for the development of molten salt storage for use on concentrated solar power units. Several groups at W&M have funded research associated with graphene for advanced battery and capacitor electrical storage, materials strengthening and corrosion resistance for hydrocarbon pipelines, and other energy applications.

James Madison University. Research includes range modeling of electric vehicles, particularly developing energy usage models of specific electric vehicles based on typical road load modeling techniques. Comparison of energy usage predictions along a particular route with actual energy usage as monitored along the route provides feedback on model efficacy. To date, electric vehicle projects with a range modeling component include: low-speed electric utility vehicle on and about campus; touring motorcycle prototype; and a cross-country endurance racer / coast-to-coast record-setting motorcycle.

JMU's VCC managed the Richmond Electric Vehicle Initiative. The main objective of this project was to advance the Richmond region as an attractive and sustainable market for electric vehicle technology and develop an electric vehicle readiness plan.

University of Virginia. In the area of conservation related to transportation energy use, the Smart Travel Lab is a joint effort between the Department of Civil Engineering and the Virginia Transportation Research Council. Part of the UVa Center for Transportation Studies, the Lab is connected to traffic management systems operated by the Virginia Department of Transportation (VDOT), providing researchers with direct access to current Intelligent Transportation System (ITS) data. This allows the Lab to help VDOT's Smart Travel Program reduce traffic congestion in the heavily populated areas of Northern Virginia and Hampton Roads.

Virginia Tech. To determine the effects of plug-in electric vehicles (PEVs) and solar generation on the grid using a networked micro-simulator, VT studied the capacity contribution of solar installations in New York City using four years of actual weather data and load curves. This study extrapolated out this information to identify an optimal installed capacity of solar generation based on the PEV penetration. Additionally, the studies conducted evaluated the introduction of wind and solar in the presence of PEVs.

The intersection of transportation and energy provides opportunities to reduce energy consumption and GHG and enhance energy independence. Virginia universities are engaged in multiple areas of research, including fuel cell membranes and materials (Virginia Tech), electric vehicles (James Madison University), and policy work (George Mason University).

VT developed and successfully applied a model for computing optimal mixes of wind and solar generation to achieve a given overall renewable penetration target in a geographical region based on the historical weather and load patterns and conventional generation capacity in the area. VT also developed the ability to simulate the impact of PEVs on a grid while taking into account the stochastic nature of individual vehicle movements and charging / discharging along with the specific commute characteristics of a region.

Energy R&D at Federal Laboratories in Virginia

Virginia is home to three major federal research laboratories that are conducting energy research, all of which are engaged in energy-related research and development. The laboratories surveyed for this report are:

- Thomas Jefferson National Accelerator Facility (Jefferson Lab)
- NASA Langley Research Center (NASA LaRC)
- Naval Surface Warfare Center – Dahlgren Division (NSWCDD)

Table 10-1: Sampling of Energy R&D at Federal Labs in Virginia

Sampling of Energy R&D at Federal Labs in Virginia														
FEDERAL LAB	Energy Generation / Sources & Technology									Energy Transmission & Technologies	Energy Use / Impact & Technology			Energy Policy
	Fossil Fuels	Nuclear	Fuel Cells / Hydrogen	Biofuels	Waste-to-Energy	Geothermal	Water / Hydroelectric	Solar / Photovoltaics	Wind	Electric Grid	Energy Storage	Energy Efficiency / Conservation / Environment	Buildings / Construction	Energy Policy
Jefferson Lab		•						•	•			•		•
NASA LaRC		•	•	•					•		•	•	•	
NSWCDD												•		

Thomas Jefferson National Accelerator Facility

The Jefferson Lab is a DOE-funded facility whose primary mission is to conduct basic science research on sub-atomic particles (quarks and gluons). The Lab is a world leader in accelerator technology, and its Continuous Electron Beam Accelerator Facility (CEBAF) is the world's most advanced particle accelerator for investigating the quark structure of the atom's nucleus. Jefferson Lab conducts basic and applied research with industry and university partners utilizing CEBAF. As it relates to energy research, the Lab has an interest in Accelerator Driven Systems, when an electron beam is used to drive a nuclear reactor. Research applications also include advanced energy efficiency for multiple high tech areas including cryogenic systems, utilization of high power radio frequency (RF), and integrated complex system operations. Additionally, the Jefferson Lab is a leader in the Hampton Roads Energy Corridor, a loose federation of mostly federal facilities advancing opportunities for enhanced energy security, surety, and sustainability.

NASA Langley Research Center

NASA LaRC is a research, science, and technology development center that maintains expertise in systems concepts, climate research, and vehicle technologies. Its energy-related research crosses a variety of areas, including efficiency, waste mitigation, conversion, and storage.

NASA Langley leads NASA's Environmentally Responsible Aviation project, exploring and developing tools, technologies, and concepts to improve energy efficiency and environmental compatibility, and developing concepts and technologies for improvements in the noise, emissions, and performance of transport aircraft. The Center was recently selected to lead NASA's Advanced Composites Project – a project focused on reducing the time for development, verification, and regulatory acceptance of new composite materials and design methods for aircraft.

Energy-related earth science research is principally focused on searching for and creating better ways of gathering, measuring, and analyzing atmospheric data. Atmospheric scientists conduct research from the land, sea, air, and space to understand the atmospheric effects caused by volcanic eruptions, industrial pollution, changes in the planet's energy balance and other events. The Center is working toward improving the systems that take ozone measurements close to the earth's surface, better understanding impacts to the air we breathe, and is researching ways to improve earth observations from space – the characterization of near-surface pollution. In 2015, NASA LaRC will be delivering SAGE III, an instrument to study ozone and aerosols, to the International Space Station; the Center is operating five on-orbit instruments, all focused on monitoring air pollution and improving climate models to better understand and predict earth's climate change.

Naval Surface Warfare Center – Dahlgren Division

NSWCDD's main focus is on weapons / combat systems. Its energy-related research is on high-energy lasers and improved power efficiencies.

Tobacco Commission Centers

The Tobacco Indemnification and Community Revitalization Commission is a 31-member body created by the 1999 General Assembly. Its mission is the promotion of economic growth and development in tobacco-dependent communities, using proceeds of the national tobacco settlement. Supporting that revitalization mission, the Commission established six research and development centers in the Southside and Southwest regions of Virginia. The centers include:

1. R&D Center for Advanced Manufacturing and Energy Efficiency
2. Southern Virginia Product Advancement Center (formerly Riverstone Energy Centre)
3. Center for Advanced Engineering and Research (CAER)
4. Sustainable Energy Technology Center
5. Foundation Growth Ventures (formerly Southwest Virginia Clean Energy R&D Center)
6. Appalachia America Energy Research Center

Each Center operates independently and serves the research needs of its designated area. A summary of notable work performed follows.

- Foundation Growth Ventures, a division of the Southwest Virginia Higher Education Center Foundation, invests in early-stage companies in rural Southwestern and Southern Virginia. Its funding model differs from the Commission's traditional grant funding model; the Fund invests in companies using Commission monies with the aim of growing each company and

receiving a financial return on the investment. The Fund has invested in renewables and conventional fuel technology companies, including OptaFuel, ReNew Fuels, and CavitroniX.

- The Southern **Virginia Product Advancement Center** serves as a business incubator and product development center. The Center operates a modeling and simulation center for virtual prototyping and testing and a leading-edge coating and finishing center.
- **CAER** has developed capabilities centered on the nuclear energy industry, in concert with the region's nuclear work. The Center also houses testing and analysis technologies and sensors and controls technologies for the energy industry.

Industry-based Energy R&D in Virginia

The survey uncovered an array of R&D, including focus areas in nuclear and increasingly in wind. R&D is performed by large companies, though small and start-up companies are seen as important sources of innovation. Energy technologies often have a longer development timeline, are capital-intensive, and R&D may require access to expensive equipment.

Several Virginia companies were interviewed to determine their general energy R&D interest areas. Table 10-2 summarizes energy-related R&D interests of these companies.



Table 10-2: Sampling of Energy R&D at Companies in Virginia

Sampling of Energy R&D at Companies in Virginia														
COMPANY	Energy Generation / Sources & Technologies									Energy Trans- mission & Technol- ogies	Energy Use / Impact & Technologies		Energy Policy	
	Fossil Fuels	Nuclear	Fuel Cells / Hydrogen	Biofuels	Waste-to-Energy	Geothermal	Water / Hydroelectric	Solar / Photovoltaics	Wind	Electric Grid	Energy Storage	Efficiency / Conservation / Environment	Buildings / Construction	Energy Policy
Afton Chemical												•		
Alstom Power									•					
AREVA		•												
Babcock & Wilcox		•												
Dominion Virginia Power	•	•						•	•	•		•		•
GE Energy	•	•						•	•			•		
Newport News Shipbuilding	•	•		•			•		•		•	•	•	
Opower												•		
Siemens Energy												•		
Timmons Group	•								•			•	•	•
Verdant Power							•							
SBIR / STTR Companies			•	•			•		•		•			
GAP / CEF Portfolio	•		•	•	•							•		

Similar to statistics collected for academic R&D, NSF does not monitor the “energy” industry in its business-related R&D statistics. Energy R&D, instead, is incorporated in other sectors, including electrical equipment, appliances, and components, and in machinery (engine, turbine, and power transmission equipment).

The NSF’s survey of industry R&D expenditures, *Business R&D and Innovation Survey: 2011*, reported that Virginia companies performed \$5.56 billion in domestic R&D, of which \$2.09 billion was paid for by the U.S. federal government. This report identifies select industries and classification codes; energy is not specifically called out.

Energy R&D at Selected Virginia Companies

Virginia’s private sector companies researched and interviewed are working on efforts to further their commercial practices. When and if necessary, the firms seek partnerships with Virginia-based research universities. However, these partnerships are infrequent and are driven by their

customer's needs. The companies provided limited information on their energy R&D expenditures.

Afton Chemical of Richmond is a global petroleum additives supplier. Afton Chemical sells a variety of lubricants (e.g., engine oil, fuel) to reduce wear in engine parts and improve fuel performance while reducing emissions. Afton Chemical's Ashland Technical Center is located 15 miles north of its headquarters and is researching clean-up levels of detergent additives, vehicle emission levels, and the benefits of fuels additives.

Alstom Power (Arlington), a global provider of power generation, power transmission, and rail infrastructure, maintains its turbine engineering, manufacturing, and service group in Midlothian and its Alstom's North American headquarters for wind energy in Richmond. Its wind energy activities include working with Dominion Virginia Power to install two Alstom wind turbines off the coast of Virginia as part of the Virginia Offshore Wind Technology Advancement Project supported by the DOE. In June 2014, GE purchased Alstom's gas and steam turbine business; the impact on Virginia R&D is not yet known.

AREVA (Lynchburg) has strengthened its R&D facility footprint extensively in Virginia since 2007. The AREVA Solutions Complex is home to world class labs and test facilities. In September 2012, AREVA opened its U.S. Technical Center as a major component of the Solutions Complex. The Technical Center contains a world-class seismic analysis laboratory, a chemistry lab featuring scanning electron microscopes for evaluating material properties, environmental chambers testing component and product performance, and chambers for thermal aging to support commercial grade dedication testing of safety-related components in the nuclear fleet.

AREVA maintains three principal locations in Lynchburg, including its Center of Excellence for U.S. Pressurized Water Reactors (PWR). AREVA is leading the development of its new PWR fuel design named GAIA for the U.S. nuclear fleet. The GAIA fuel design will provide utilities cost-savings through its high mechanical fretting resistance, better thermal performance, and increased tolerance to earthquakes. Moreover, the design features advanced cladding, which AREVA anticipates will meet new regulatory requirements in the United States.

AREVA is partnering with Virginia universities, in collaboration with the DOE, to develop a new fuel cladding that improves heat transfer characteristics. Moreover, AREVA partners with VCU, UVa and Virginia Tech. At VT, AREVA is on the College of Engineering Advisory Board as well as on the Nuclear Engineering Advisory Board. At UVa, AREVA has worked on wind energy development and on laser advanced manufacturing.

AREVA's fuel division spent more than \$10 million in fuel design-oriented research and product development activities in 2013 in Virginia. Further, the company spent approximately \$9 million on R&D in Virginia through its "Installed Base" business unit.

Babcock & Wilcox (B&W) maintains business operating units in Lynchburg, including mPower (development and deployment of small modular reactors), Nuclear Energy and Nuclear Operations (manufacturing and services for commercial nuclear applications and government applications, respectively) and Technical Services (nuclear operations and technical services for the government). The company partnered with CAER in Bedford County to develop and host the mPower Integrated Test Facility and, where a digital control room simulator is housed, the Center of Excellence for Safe and Secure Nuclear Energy. In Virginia, B&W conducts

commercially-focused R&D in areas such as testing and evaluation of nuclear applications and materials and non-destructive evaluations.

Dominion Virginia Power's most public R&D effort pertains to the development of the offshore wind turbine demonstration project off the coast of Virginia. The \$51 million project was funded by DOE to help with the construction of a 12-megawatt demonstration project, consisting of two 6-megawatt wind turbines. In addition, the company invested roughly \$1.7 million in 12 renewable energy R&D grants to Virginia-based universities and colleges in areas such as wind turbine design, bio-mass, and green-roofing.

In June 2014, GE purchased Alstom's gas and steam turbine business. Prior to the acquisition, the foci of **GE Energy's** Salem facility were expertise in controls and power electronics, and providing technology, software, and hardware needed for the reliable and efficient operation of GE's turbines, generators, compressors, and power conversion equipment for these and the wind, photovoltaic, and oil and gas markets.

Newport News Shipbuilding (a division of Huntington Ingalls Industries) is heavily involved in the development, manufacturing and construction of America's next-generation aircraft carriers and submarines. Its R&D of energy-related technologies directly relates to enhancing manufacturing, and construction of these core products. Areas of interest include improving energy efficiencies, small modular reactors, nuclear waste clean-up, transportation of nuclear waste, and wave energy. Newport News Shipbuilding also manages the Virginia Advanced Shipbuilding and Carrier Integration Center (VASCIC) established in 1998 by the Commonwealth. The purpose of VASCIC is to enhance and promote the quality and competitiveness of Virginia's shipbuilding industry and to promote the general welfare of Virginia citizens. At VASCIC, Newport News Shipbuilding, along with electronic system suppliers, software suppliers, U.S. Navy laboratories and program representatives, and Virginia institutions of higher learning, develop and integrate new technologies for aircraft carriers and advanced shipbuilding.

Opower (Arlington) is developing cloud-based solutions for utility companies to improve customer engagement and their energy use. Opower delivers a platform for utilities to engage their customers by using data mining techniques and behavioral sciences. Through its software, utilities are able to analyze their customers' energy usage and send targeted messages (alerts) indicating potential upcoming high usage patterns, thus enabling users to understand and manage their energy usage on an ongoing basis.

In 2013, **Siemens Energy** opened a manufacturing facility in Charlottesville for the commercial production of airfoil ceramic cores for gas turbine blades and vanes, utilizing technology developed by Mikro Systems, Inc. These developments are expected to improve cooling capabilities of gas turbine blades leading to higher efficiency levels.

Timmons Group, headquartered in Richmond, provides engineering services to clients on a custom basis. The company was awarded program management and site and regulatory work for the Virginia offshore wind power development project.

Verdant Power, one of three leading tidal turbine manufacturers, is headquartered in Arlington and is producing underwater turbines for deployment in a tidal stream demonstration project in New York City's East River.

SBIR / STTR Energy Research in Virginia

CIT identified 20 Virginia companies that have received federal energy-related SBIR or STTR awards in the last three years. These companies, and their research areas, are listed below:

- Aurora Flight Sciences Corporation, Manassas – high-efficiency propulsion
- Cell-Free Bioinnovations, Inc., Blacksburg – high-yield hydrogen production from biomass sugars by cell-free biosystems for mobile electricity generation (spin-off from Gate Fuels in November 2012)
- Columbia Power Technologies, LLC, Charlottesville – wave energy converter performance and cost optimization
- Craftell Power Sources, LLC, Fairfax Station – reserve cell technologies with fast initiation for power on demand
- Directed Vapor Technologies International, Charlottesville – processing methods for manufacturing multifunctional high-temperature coatings; coatings for turbine airfoils (based on UVA research)
- Edenspace Systems Corporation, Purcellville – poplar system for remediation of organic contaminants
- Gate Fuels, Inc., Blacksburg – production of formic acid powered by sugars; development of high-power and high-energy-density enzymatic fuel cells as a next-generation, environmentally friendly (micro-)power source
- GeneSiC Semiconductor, Inc., Dulles – silicon Carbide Quasi-Bipolar Junction Transistor (QBJT)-based boost converter platform for up-tower wind applications; advanced power modules for use in power electronics for energy storage in the medium-voltage range
- IRFLex Corporation, Danville – fiber delivery systems for ultrashort pulse lasers
- Luna Innovations, Inc., Roanoke – nanostructured carbon nanosheet electrode for enzymatic fuel cells; bio-responsive antifouling coatings for ship hull; battery management system for monitoring and diagnostics of energy storage modules; rechargeable batteries with advanced non-toxic and safe anode and cathode materials; embedded fiberoptic shape-sensing for aeroelastic wing components
- Materials Modification, Inc., Fairfax – next-generation processes for carbonate electrolytes for battery applications; new solvent system for CO₂ capture
- MicroXact, Inc., Christiansburg – real-time manufacturing diagnostic system for the photovoltaic industry; next-generation thermoelectric devices (based on VT research)
- Mikro Systems, Inc., Charlottesville – rapid manufacturing method for high-temperature turbine components
- Muplus, Inc., Newport News – muon collider cooling channel design and simulations
- NanoSonic Inc., Pembroke – encapsulation approaches for flexible solar panels, displays, and antennas; VOC-free, highly flame-resistant insulation coatings for next-generation thermal insulation and energy efficiency (based on VT research)
- Polymer Exploration Group, LLC, Midlothian – low-cost and durable ice-release coating to mitigate icing-related problems encountered by air transportation, power transmission, and wind energy industries (based on VCU research)

Energy R&D at CEF / GAP Portfolio Companies

Energy industry R&D performers include start-up companies with high-growth potential that have attracted external investment. Several of these companies are in the CIT investment portfolio and received investments from the CIT's Commonwealth Energy Fund (CEF) or the Growth Acceleration Program (GAP) Fund, accelerating the firms' pathways to significant growth through active partnership and company development. A sample cross section of portfolio companies appears below:

- Wiretough Cylinders, LLC, Bristol – developing and demonstrating a low-cost, high pressure hydrogen storage vessel using a steel wire overwrap with a \$2 million grant from DOE
- Marz Industries, Glen Allen – focused on improving fuel efficiency through better hydrogen fuel cells, for ruggedized use in commercial short- and long-haul trucking applications
- Sunnovations, McLean – performing research to enable low-cost, smart-control of water heater energy usage; an emerging technology, enabled by development of an enthalpy sensor, allows for leak detection, water main shutoff, behavioral energy efficiency management, and utility demand response
- CavitroniX, Bristol – developing in-line technology and reducing greenhouse gas and soot emissions from oil fired boilers and furnaces, diesel generators, and marine diesel engines
- Piedmont Bioproducts, Gretna – uses renewable, farm-based feedstocks to generate clean biofuels through use of a thermo-chemical process